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THE EFFECT OF OXYGEN ENHANCEMENT ON HAZARDOUS WASTE INCINERATION

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ABSTRACT

How does the addition of Oxygen improve the applicability of incineration? This paper addresses that question by evaluating the performance of oxygen enhanced hazardous waste incineration in three different applications. The cases studied include a laboratory study of the use of oxygen in reducing the transient emissions produced when solid waste is fed to a rotary kiln, a direct comparison of oxygen-enhancement to air only incineration using a mixture of hazardous wastes in a 3 million BTU/hr rotary kiln, and the use of oxygen-enhancement to decontaminate dioxin contaminated soil from seven uncontrolled waste sites. Results indicate that, oxygen-enhancement can significantly increase the throughput rate of low heating value wastes while still achieving successful decontamination. For high heating value wastes, additional modifications are required to reduce the temperature increase that accompanies oxygen enhancement. This rise in temperature causes increases in NOx, soot, and unburned hydrocarbon emissions.

INTRODUCTION

Over 120 Million Kg of hazardous waste are produced annually in the United States. Of that, 21 million Kg, or roughly 18%, is amenable to incineration. Only 1.2 million Kg, or 1%, is currently incinerated at 221 incinerators nationwide.[1] Among the reasons behind the low utilization of incineration are a concern over air emissions and the relatively high cost of incineration compared to other means of waste management.

Despite these concerns, incineration may be more widely used in the future. Concerns about long term liability have decreased the desirability of land disposal and increased interest in waste management techniques that result in destruction. In addition, increasing restrictions on the amounts and types of waste that can be landfilled are also increasing interest in more permanent disposal techniques. Since incineration has been shown to be a proven, readily available and effective technique for disposing of a wide variety of hazardous wastes, it is often the alternative of choice when landfilling is no longer available.

The United States Environmental Protection Agency (EPA) has been studying hazardous waste incineration for the past 10 years and is still doing so in an effort to minimize air emissions from hazardous waste incinerators and to better detect them when they do occur. When oxygen enhancement was suggested as a potential process improvement to hazardous waste incineration, EPA investigated.

Oxygen enhancement involves the addition of a stream of gaseous oxygen to the combustion air to augment the concentration of oxygen available for waste incineration. Potential benefits to be derived from oxygen enhancement include a reduction in emissions resulting from process upsets and an increase in waste feedrate.

In this paper, oxygen enhanced hazardous waste incineration is evaluated through the results of three different studies ranging from a laboratory study of the effect of oxygen enhancement on transient air emissions to a full scale cleanup of over 4.5 million Kg of dioxin contaminated soil. After a description of the three studies and the results obtained from each, some general conclusions regarding the use of oxygen enhanced incineration of solid hazardous waste will be discussed.

DESCRIPTION OF THE THREE CASE STUDIES

Table 1 summarizes the conditions under which oxygen enhancement was studied. As can be seen from Table 1, the three studies conducted evaluated oxygen enhancement on small, medium and large scale equipment and with high, medium and low heating value waste.

TABLE 1
Summary of Case Studies

Case	Kiln Size KW	Feed Rate Kg/hr	Heating Value KJ/Kg	%Excess Air*
A	73	N/A	42358	10-100
B	880	95	23244	330-400
C	2343	1818	465/13920	50 @

*Calculated as though only air was used as the combustion gas.
@Reference 8

The three studies are all similar in that the added oxygen was

used with conventional fuels to indirectly heat the solid waste, which was fed separately. In addition, in each of the three cases, extensive sampling of all feed and effluent streams was conducted.

The cases differ in that oxygen was added to the incoming air stream in both cases A and B and oxygen was added separately in case C. In fact, in case C, oxygen was the only combustion gas fed into the rotary kiln itself while air was fed into the afterburner. More description is provided below.

Case A

In case A, a prototype oxygen burner was installed on a 73 KW rotary kiln simulator at the EPA's Air and Energy Engineering Research Laboratory in Research Triangle Park, North Carolina. The kiln was designed to model the physical and chemical processes occuring in full-scale incinerators while still allowing the access and flexibility required for experimentation.[2] A schematic diagram of the rotary kiln simulator is shown in Figure 1. As shown in Figure 1, the interior of the kiln contains a recess measuring 0.762, in inside diameter. Solid waste fed to the kiln rests in this recess for added residence time.

This test was part of a larger study to determine the nature of the transient emissions that result from the discontinuous feeding of solid waste to rotary kiln and had as its specific purpose the determination of the effect that oxygen has on these emissions.

These transient emissions, also called "puffs", result from the rapid volatilization and reaction of organic material off of the surface of solid wastes fed to the kiln. The suddenness of this phenomenon results in the momentary depletion of oxygen from the kiln atmosphere. The resulting pyrolysis causes the formation of soot and the concomitant emission of associated volatile and semivolatile products from the kiln. This is undesirable and may even result in unstable kiln operation.

Early studies using High Density Polyethylene (HDPE), Low Density Low Density Polyethylene (LDPE), Polystyrene (PS) and Polyvinylchloride (PVC) indicated that waste type, charge mass, cahrge surface area, and kiln temperature all affected the intensity of the "puffs" produced.[3] As kiln temperature increased, the "puffs got larger. High excess air levels did not reduce the intensity of the "puffs" except when the high air flow rates produced a cooling effect which reduced kiln temperature.[3,4] In addition, chemical analysis of the "puffs" indicated the presence of toxic pyrolysis products, in some cases including dioxins and furans.[3,4]

Additional tests also investigated transient emissions produced when liquid wastes were adsorbed onto solid waste. In these studies, toluene, methylene chloride carbon tetrachloride and No.5 Fuel Oil were adsorbed onto ground corncobs and fed to the rotary kiln simulator under the same conditions as in the previous tests on solids. In these tests several different methods were used to measure the transient emissions produces. Carbon monoxide and total unburned hydrocarbon peak height and peak areas were used to quantify transient emissions of volatile organic chemicals. Soot captured on particulate filters was used to quantify transient particulate emissions. These studies confirmed the conclusion reached earlier that increased kiln temperature worsened the transient emissions caused by "puffing".[4,5]

The effect of oxygen enhancement on transient emissions from "puffing" was studied using toluene adsorbed onto ground corncobs, as in the previous study. As before, this material was fed to the rotary kiln simulator and the transient volatile and particulate emissions were measured. This time, however, an oxygen/air burner capable of providing from 22% to 100% oxygen was installed on the rotary kiln simulator. A series of tests were conducted to determine whether the addition of oxygen to the combustion air stream reduced or changed the emissions produced from "puffing".

Case B

The second case involves the installation of a larger version of a larger version of the prototype burner used in case A on an 880 KW rotary kiln incinerator at the EPA's Combustion Research Facility (CRF) in Jefferson, Arkansas. These tests were conducted as part of the EPA's Superfund Innovative Technology Evaluation (SITE) program. The purpose of this study was to evaluate the effectiveness of the burner, and, more generally oxygen enhancement, in decontaminating hazardous waste. An eight week series of tests was conducted in which oxygen enhanced operation was compared to air-only operation using a mixture of decanter tank tar sludge and contaminated soil from the Stringfellow Acid Pits, a contaminated hazardous waste site in Riverside, California. Table 2 lists the major chemical contaminants of the waste tested.

TABLE 2
Contaminant Concentration Estimates [6]

Concentration Estimates ug/g		= 95% Confidence Interval*
Naphthalene	62	= 5.4
Acenaphthylene	15	= 2.7
Fluorene	7.6	= 1.8
Phenanthrene	28	= 3.4
Anthracene	8.3	= 1.8
Fluoranthene	14	= 2.2

* Averages and confidence intervals are derived from analyses of eight separate composite samples of waste.

Figure 2 shows the rotary kiln at the Combustion Research Facility and the location of the air/oxygen burners. Two burners were installed on the kiln, one on the kiln itself and one on the afterburner. A proprietary process control system controlled the air/fuel/oxygen ratio for each burner and made adjustments based on carbon monoxide and oxygen readings taken in the duct between the kiln and afterburner.

For these tests, the maximum solid waste feed rate was determined by gradually increasing the charge mass and increasing the charge frequency until puffing reached a predetermined intensity or until the system became unstable. Analyses of the feed and all effluent streams were then conducted at the highest stable feedrate for both the air only and oxygen enhanced conditions. This provided a basis for the comparison and evaluation of oxygen enhancement. Throughout each test the stack gasses were continuously monitored for carbon monoxide, carbon dioxide, oxygen, total unburned hydrocarbons and nitrogen oxides.

Case C

This case involves the use of oxygen enhancement in the cleanup of a dioxin contaminated site in Missouri. Since 1985, the EPA's Mobile Incineration System (MIS) has been installed on the Denney Farm site in Southwest Missouri near the city of McDowell. This site was contaminated with dioxin as the result of improper disposal of wasted from pesticide manufacture. For the past four years the MIS has been cleaning up contamination from that site and from seven others in the vicinity. Thus far, over 4.5 million Kg of dioxin-contaminated soil has been treated.[1,7]

Figure 3 is a schematic diagram of the MIS, which features a 2343 KW rotary kiln. At first, no oxygen enhancement was used in this system. Although the incinerator was proven capable of decontaminating the soil, a deliberate decision was made to install an oxygen burner on the rotary kiln in order to increase the throughput rate of the incinerator and ultimately to speed the cleanup of the dioxin contamination in Southwest Missouri. [10]

The oxygen burner used in this case supplied 100% Oxygen to the kiln. A conventional air burner was used in the afterburner. The oxygen burner selected for use on the MIS was designed differently than the burners used in the previous two cases. In this burner, combustion gases are aspirated into the flame envelope. This reduces the flame temperature and the potential for high NOx formation.

By reducing the nitrogen in the combustion air stream the volume of combustion gas was significantly reduced. Even at an elevated waste feed rate, enough oxygen could be supplied to maintain a sufficiently oxidative environment to incinerate the waste without reducing the residence time in the afterburner to below the legally required 2 seconds. This reduced combustion gas volume also reduced the carryover of particulate from the kiln to the afterburner.[10]

RESULTS

The results of these three tests of oxygen enhancement show that oxygen can either help or hinder hazardous waste incineration depending on how it is used.

How Oxygen Helps to Improve Incineration

Oxygen enhancement can allow for significant increases in throughput rate when solid waste with a low heating value is being treated. In case C, the throughput rate of dioxin contaminated soil was increased from 909 Kg/hr to 1818 Kg/hr. This was possible because oxygen enhancement decreased the total volume of combustion gas required per ton of waste processed due to the displacement of nitrogen. The decreased combustion gas volume eliminated operational problems such as particle entrainment, excessive gas velocity, and excessive nitrogen cooling all of which limit the capacity of incinerators operating with only air.

Oxygen enhancement is also more cost effective for low heating value fuels. This is because low heating value wastes require more fuel to incinerate. Oxygen enhancement, by reducing the amount of nitrogen in the combustion gas stream, reduces heat loss and therefore makes more efficient use of fuel. This can result in significant fuel savings. At Denny Farm, the fuel required per ton of waste processed was reduced by 50%.[8]

When wastes with higher heating values are used, the throughput rate can be increased, but with some difficulty. In the SITE demonstration of the Pyretron at the Combustion Research Facility, the feed rate was increased from 105 lb/hr to 210 lb/hr, but only with the injection of 37.4 l/hr water to remove the excess heat. This was because the heating value of the waste, at 23244 KJ/Kg was high enough to reach the practical heat release limitations of the kiln at these feed rates. Without high levels of nitrogen to absorb some of this heat, temperature excursions resulted which in turn led to operational difficulties. To alleviate this problem water was injected into the air stream in order to absorb some of the excess heat generated and to restore process stability.

This effect was also observed in case C. At Denney Farm, the throughput increases achieved when soil was treated with oxygen in the MIS were lost when 13920 KJ/Kg sludge was treated. In that case, even with water injection, throughput was limited to 909 Kg/hr. [8,11]

How Oxygen Hinders Incineration

The temperature increase that accompanies the use of added oxygen is detrimental in the following ways. As alluded to above, the higher temperatures limit capacity. Without the added heat sink

provided by the nitrogen in air, the thermal capacity of the incinerator is quickly reached unless an alternative heat sink, such as water, is provided. Sometimes that does not eliminate the problem, as was the case for sludge incineration in case C.

Contrary to expectations, the high temperatures resulting from oxygen enhancement increased the release of volatile organic chemicals and soot during transient puffing episodes.[2,4,5] It had been assumed that the added oxygen available for combustion would decrease the emissions from transient events caused by a momentary lack of oxygen. However, the added oxygen available from oxygen enhancement was insufficient to compensatefor the increased load of organic material that volatilized into the combustion gas during such events. Pyrolysis still took place and unburned hydrocarbons and soot were still emitted. The elevated temperatures that result from oxygen enhancement merely made more organic material volatilize during "puffing". This increased transient emissions.

Transients were anticipated during case B. Although they did occur, they were not as extensive as originally anticipated. Further, their occurrence was too infrequent to study in great detail. As a result, no conclusions were drawn as to the effect oxygen enhancement may have had on transient emissions in case B. Part of the reason for this is that "puffs" do not occur regularly when a heterogeneous waste stream is fed to the kiln. In the studies reported in case A, "puffs" were deliberately created in a very controlled was using single component feed streams. Ther heterogeneous mixture of chemicals fed in case B can and do form "puffs". They do so suddenly and without much warning, however,. This makes "puffing" difficult to study outside of the laboratory.

Higher temperatures also increase NOx formation In all three studies, higher temperatures resulting from the use of oxygen enhancement resulted in higher NOx emissions. For case A the dominant factor in increasing NOx levels was increasing oxygen enhancement.[2] In case B NOx levels increased from roughly 150 ppm when no oxygen enhancement was used to over 2000 ppm when oxygen enhancement was used. For some tests with oxygen enhancement, however these high NOx levels were reduced to below 250ppm. Table 3 shows NOx levels for the air only and oxygen enhanced test runs for case B

TABLE 3
NOx Levels for Air-Only and Oxygen-Enhanced Operation
For Case B [6]

Air/Oxygen	Ave.NOs Level	Std.Deviation	High/Low	%Excess Air
Air	101 ppm	17.0 ppm	130/75 ppm	197
Air	80.64	17.3	120/55	117
Air	117	17.6	150/90	
Oxygen	1753	337	2150/1100	438
Oxygen	1064	225	1450/750	335
Oxygen	750	485	1600/350	377
Oxygen	725	234	1300/200	395

In case C, NOx emissions were not as high because, as mentioned earlier, the oxyglen burner employed there was desibned to reduce the temperature increase that normally results from oxygen enhancement. This was done by aspirating combustion gasses into the flame envelope. Levels of NOx averaged 126-166 ppm when the system was operated only with air and 54-138 ppm when oxygen enhancement was used.[9]

Oxygen Neither Increased Nor Decreased The Extent of Waste Destruction

The three incinerators sutdied were all capable of successfully decontaminating waste streams without the addition of oxygen. Destruction and Removal Efficiencies (DREs) calculated for the case A indicate that 99.99% of the feed stream was successfully incinerated. without oxygen enhancement.[3] For case B, no detectable levels of organic contamination were detected in the stack gasses, the ash, or the scrubber water even when no oxygen enhancement was used.[6] Table 4 shows the DREs achieved during case B.

TABLE 4
Destruction and Removal Efficiencies
For Case B [6]

Mode	Naphthalene	Acenaphthalene	Fluorene	Phenanth*.	Anthracene	Fluoranthene
Air	99.99934	99.9975	99.99945	99.9985	99.9951	99.9979
Air	99.99936	99.9976	99.9947	99.9986	99.9953	99.9980
Air	99.99924	99.9967	99.9933	99.9984	99.9945	99.9974
Air	99.9964	99.9841	99.968	99.9920	99.9735	99.9875
O2@	99.99896	99.9955	99.9937	99.9979	99.9933	99.9989
O2	99.99978	99.99910	99.99981	99.99948	99.9983	99.9989
O2	99.99989	99.99958	99.99914	99.99976	99.99922	99.99949
O2	99.99990	99.99961	99.99919	99.99977	99.99927	99.99952
O2	99.99991	99.99965	99.99930	99.99980	99.99935	99.99953
O2	99.99990	99.99961	99.99923	99.99978	99.99929	99.99948

*Phenanth. = Phenanthrene
@O2 = Oxygen enhancement
Data are the results of 5 tests. Duplicate samples were taken during each test. Air = no oxygen enhancement. None of the above chemicals were detected in the exhaust gas. Data reflect the detection limits of the analytical methods used.

In case C, the MIS had shown successful destruction of dioxin contaminated soil and had been operating for 1 year burning dioxin contaminated soils prior to the addition of oxygen enhancement. Had these incinerators been unable to successfully decontaminate waste without added oxygen, it is unclear whether oxygen enhancement would have enabled them to do so.

CONCLUSIONS

The addition of oxygen can aid in the incineration of hazardous

waste if used properly. Added oxygen has not been shown to universally enhance hazardous waste incineration nor has it been shown to correct design flaws in the original incinerator. Oxygen enhancement can best be used in situations in which the negative effects of the temperature rise can be minimized.

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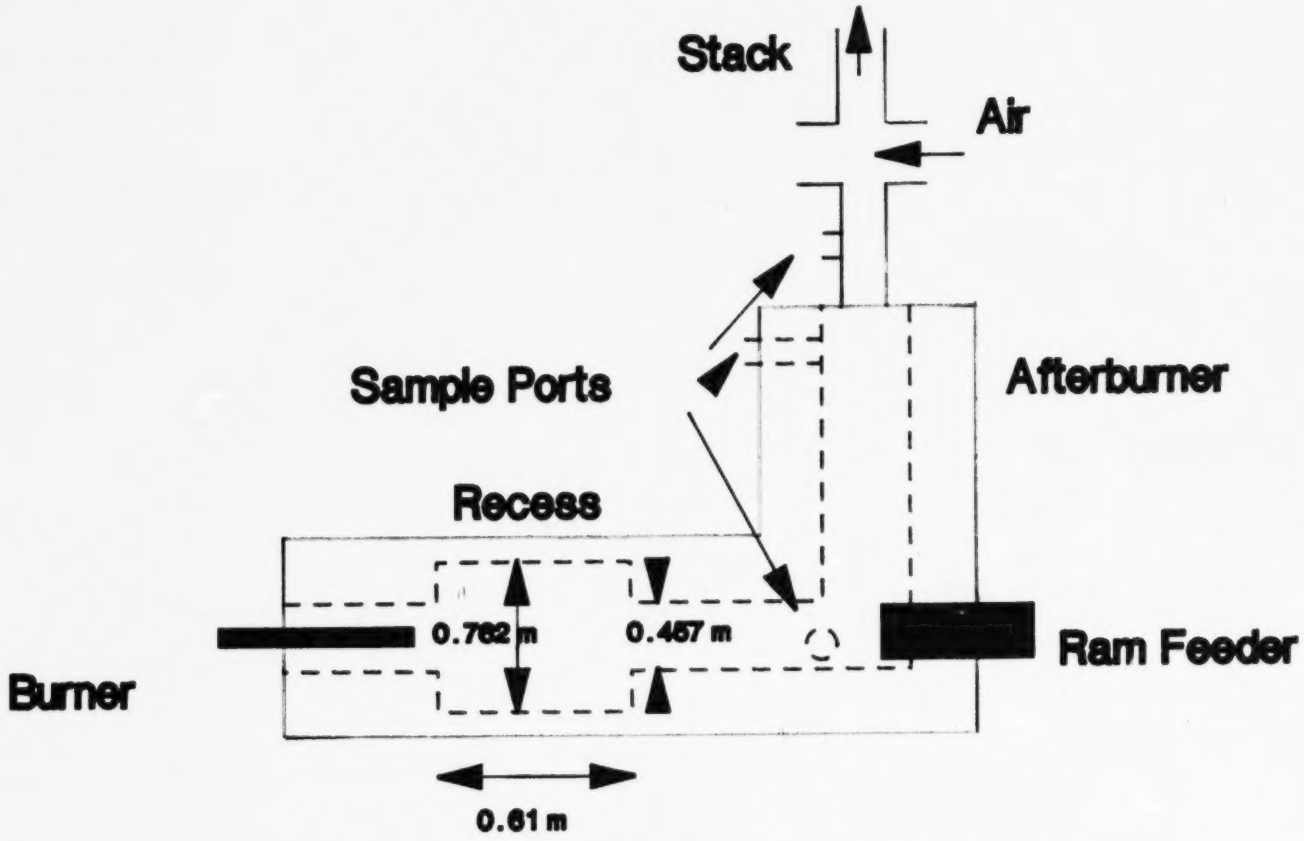

FIGURE 1 73 KW Rotary Kiln Simulator

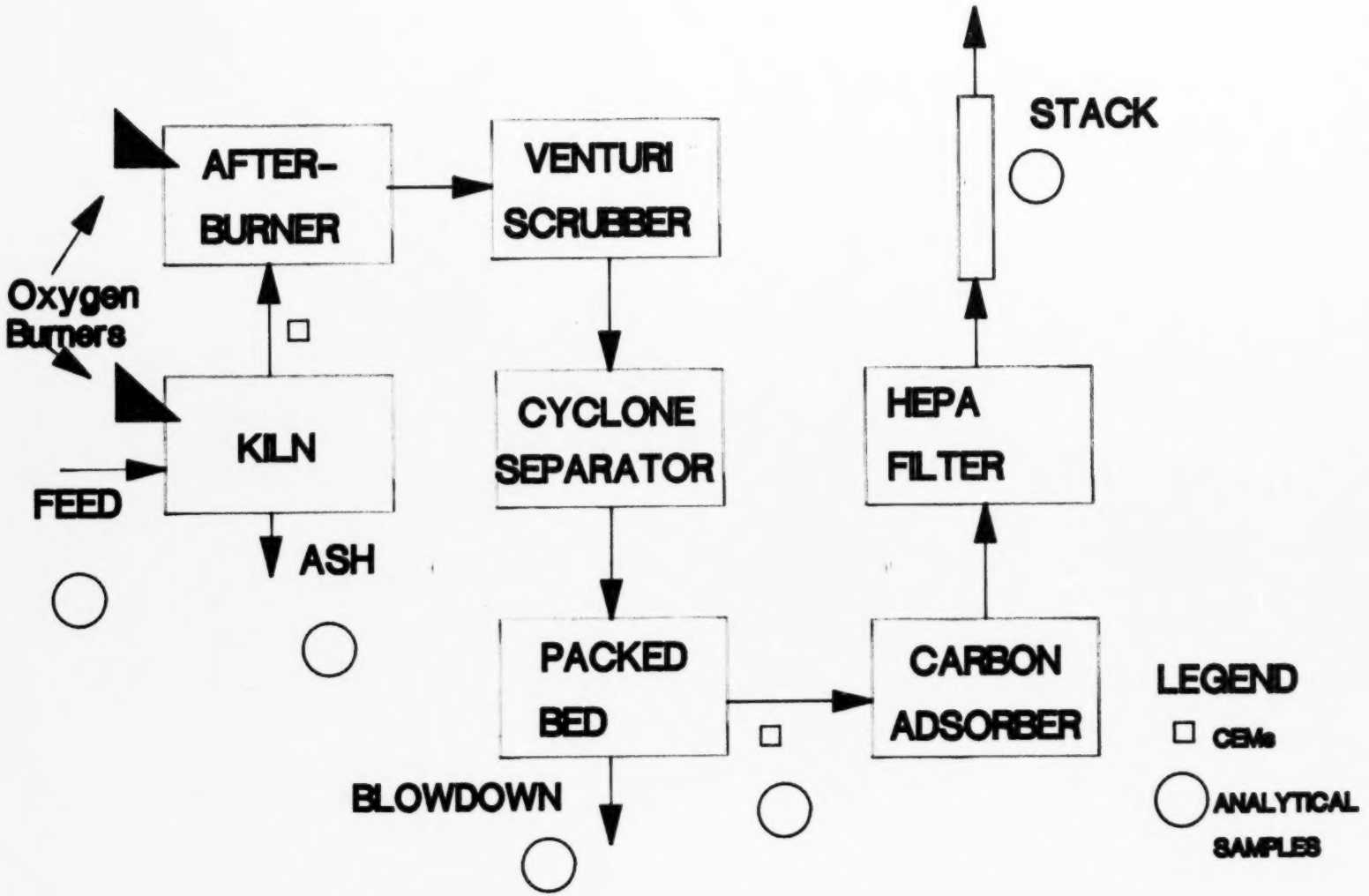

FIGURE 2 ROTARY KILN SYSTEM AND SAMPLING LOCATIONS

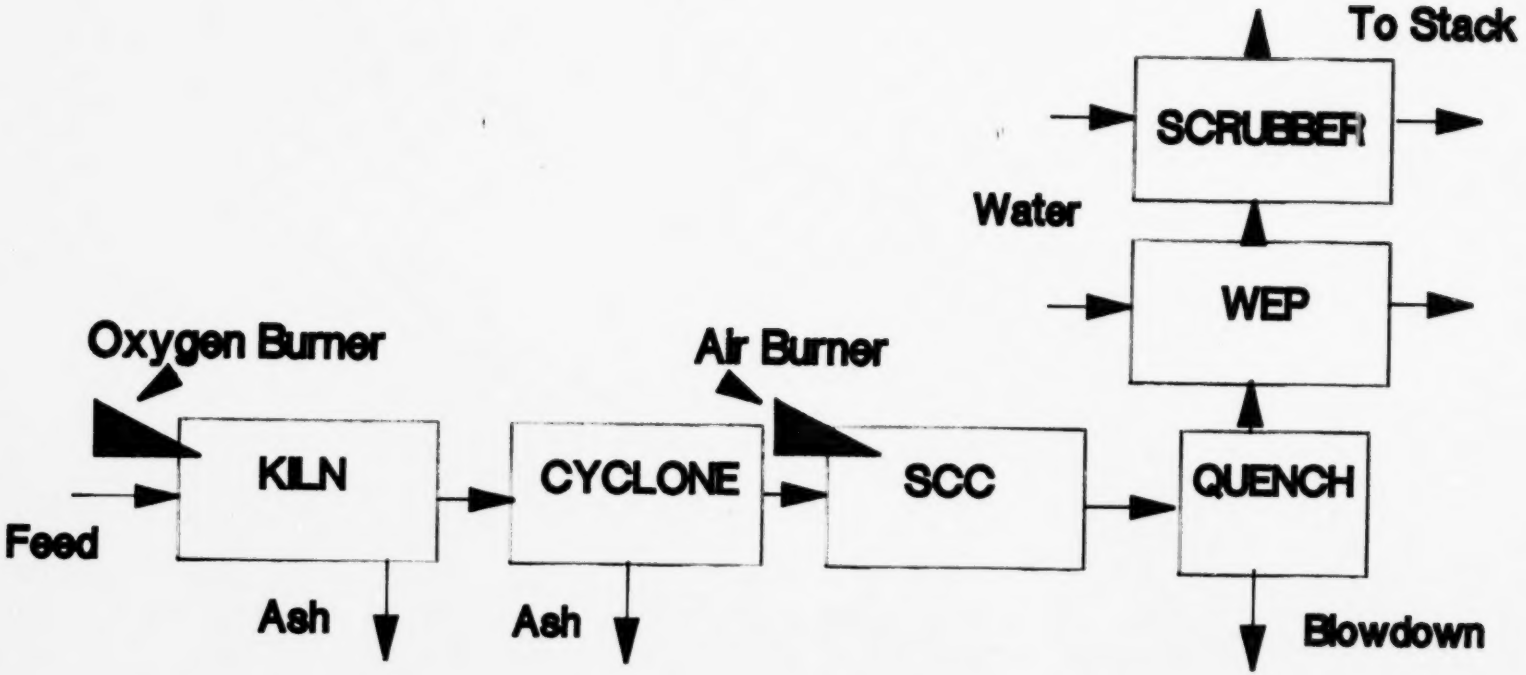

FIGURE 3 Mobile Incineration System